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REPORT R-1392

EFFECTIVENESS OF SMALL ARMS INCENDIARY AMMUNITION AT HIGH ALTITUDES (U)

Project TS1-47

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OBJECT

To summarize and review aerial combat statistics and controlled drone firing tests in order to determine the effectiveness of small arms HEI and incendiary ammunition at high altitudes.

SUMMARY

At the request of the Aircraft Gun Ammunition Blast and Incendiary Steering Committee, a research study was conducted on the ignition of aircraft fuel by HEI and incendiary ammunition at high altitudes.

The F6F drone tests conducted at the U. S. Naval Aviation Ordnance Test Station, Chincoteague, Va., demonstrated that ignition and sustained burning can be obtained at an altitude of 34,000 feet with all rounds tested (caliber .50 M23, caliber .60 T36 and T39, and 20 mm M96), except the 20 mm M97, when using 115/145 octane gasoline. This altitude represents the operating ceiling of the control and photographic aircraft. JP-1 fuel was the most resistant to ignition of sustained fires and JP-3 fuel the most vulnerable to ignition and propagation of fire. In addition, JP-3 fuel appeared to burn at a higher temperature than the other two test fuels, as evidenced by the greater destruction wrought by approximately equal amounts of fuel.

The B-17 drone tests, conducted at the Air Force Armament Center, Eglin Air Force Base, Florida, demonstrated that caliber .50 M23 incendiary ammunition is capable of initiating and sustaining a destructive fuel fire at altitudes up to 35,400 feet under multiple-shot conditions. Likewise, it is evident that external purging of the fuel cell areas is not effective in preventing sustained fires under the same test conditions.

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Trapeze target tests conducted at Eglin Air Force Base have shown that ignition of sustained fires at high altitudes with incendiary ammunition is heavily dependent on target conditions. Evaluation of ammunition must depend on the target configuration. However, under identical conditions of simulated tests, it has been shown that ammunition containing zirconium incendiary mixtures produced sustained fuel fires at higher altitudes than did ammunition containing conventional mixtures.

A detailed study was made of the air-to-air combat in Korea by the Institute for Air Weapons Research, University of Chicago. The survey covered many aspects of air warfare, such as searching, positioning, and firing phases. It is seen from this study that data obtained from the Korean conflict confirmed results from World War II statistics, pointing to the vulnerability of aircraft to incendiary ammunition at high altitude.

In combat film of one-hit attacks which resulted in MIG-15 kills, approximately one-half evidenced some burning phenomena. From these data and from combat altitude firing data, it is certain that fire phenomena were associated with kills at combat altitudes of over 30,000 feet. Two official awards have been made for MIG kills, with attendant fire phenomena, at altitudes (reported by the combat pilots) in excess of 40,000 feet.

AUTHORIZATION

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INTRODUCTION

A recognition of the gravity of the fuel-fire problem in aircraft, together with a consideration of the damaging potential of small arms incendiary ammunition at high altitudes, prompted the Aircraft Gun Ammunition Blast and Incendiary Steering Committee to recommend an investigation into the effectiveness of small arms incendiary ammunition at high altitudes. This investigation comprised an assessment of pertinent aerial tests under actual and simulated conditions and an evaluation of incendiary ammunition under actual combat conditions.

Assessment was made of pertinent aerial tests conducted at the Air Force Armament Center, Eglin Air Force Base, Florida, involving B-17 drone aircraft and trapeze target firings, and F6F drone firings at the U. S. Naval Aviation Ordnance Test Station, Chincoteague, Va.

A detailed study of the air-to-air combat in Korea has been made by the Institute for Air Weapons Research, University of Chicago. This study involved the analysis of combat gun camera film records. These films, together with other aerial combat data, provided a source of information from which valid inferences concerning the effect of small arms incendiary ammunition can be made.

Other parameters in an analysis of the high altitude effectiveness of incendiary ammunition are necessarily involved, namely, laboratory firings (such as actual altitude, inert atmosphere, and stratosphere chamber tests) and the many theoretical considerations associated with the fuel-fire problem at high altitude. These and other aspects of the problem will be included in a comprehensive report of the development of small arms incendiary ammunition prepared under contract by Denver Research Institute, and soon to be issued by this arsenal.

TESTS - AERIAL FIRING AT MOVING TARGETS

Analysis

Firings against aircraft and simulated aircraft targets at various altitudes under flight conditions have been performed. These tests involved the use of F6F drone aircraft, B-17 drone aircraft, and trapeze targets as test media. All firings described in this report were performed during the period 1948 to 1955.

Tests at Naval Aviation Test Station, Chincoteague

The purpose of F6F drone aircraft tests, conducted from June 1949 to March 1950, was to investigate the effect of firing caliber .50, caliber .60, and 20 mm incendiary ammunition at drone aircraft being operated with three types of aviation fuels at altitudes from 30,000 to 40,000 feet. This study included the testing of caliber .50 M23 incendiary (T48), 20 mm M97 HEI (T23), 20 mm M96 incendiary, caliber .60 T36 incendiary, and caliber .60 T39 API ammunition in combination with each of the following types of aviation fuel:

Octane gasoline 115/145 (Spec AN-F-48)
Jet fuel JP-1 (Spec AN-F-32)
Jet fuel JP-3 (Spec AN-F-58)

Two basic methods of testing were used, both employing controlled drone aircraft. Air-to-air firing at a portion of the wing panel of the drone aircraft containing fuel cells was first tried, followed by a fixed gun system wherein the firing weapon was mounted in the cockpit of the drone aircraft, remotely controlled and directed at the fuel cell located in the wing panel.

The gun and ammunition compartments in the starboard and port wings of the target drone aircraft F6F-5K were used to store the fuels tested. The first four firings were air-to-air and were conducted from above and astern at a range of approximately 200

yards. This method was abandoned in favor of mounting the pre-armed gun in the cockpit of the drone aircraft. This latter method proved more satisfactory.

The target conditions are described below.

Air-to-Air Firing. Approximately 25 gallons of fuel were used, contained in one- and five-gallon cans and placed in the starboard wing gun and ammunition compartments. The distance from the trailing edge of the wing (function plate) to fuel containers and the type of materials used for the containers were not stated in report. The number of projectiles per flight varied from five to fifteen rounds per burst (multiple shots). An F6F-5 type aircraft, with two caliber .50 M2 machine guns parallel boresighted and mounted at the outboard stations, was used as the firing plane.

Fixed Gun Firing. Fifteen and one-half gallons of fuel were used in a 15 1/2 gallon tank (constructed of 18-gage galvanized steel sheet) placed in the port wing gun compartment. The firing weapon was mounted . the cockpit of the drone aircraft and actuated by remote control. The number of projectiles per flight varied from three to six rounds per burst (multiple shots).

A multiple-shot technique was used in all of these tests and, in view of this, it was not possible to determine which shot caused ignition (if it occurred) and what would happen if only a single shot were fired. The results of the tests do indicate that fires can be initiated by incendiary ammunition at altitudes of 29,400 to 34,000 feet at indicated air speeds of 110 to 150 knots, and once initiated, they can be sustained to a damaging degree. The data reported are presented in Table I.

A review of the data shows that high altitude ignition and sustained burning can be obtained with all rounds tested, except the M97, when using 115/145 octane gasoline. JP-1 fuel was the most resistant to ignition of sustained fires. The results obtained with JP-3 fuel show that it will ignite and that sustained burning can be obtained with all rounds tested except the 20 mm M97.

Table I. PDF Drone Firing Tests at U. S. Naval Aviation Ordnance Test Station, Chincoteague, Va.

Date of Mission	Gun	Ammunition	Type Fuel	No. of Rounds Fired	Hits Observed	True Altitude (ft)	Indicated Air Speed (knot)	Ambient Temp (°C)	Remarks
						Air-To-Air Firing			
3 Jul 49	Cal .50 M3	M23 T48 API	115/145	20	0	33,000	110	-15	No hits observed in target area
6 Jul 49				30	3	32,500	110	-20	Hits observed; evidence of ignition; lost airplane at sea
8 Jul 49				85	1	32,500	120	-20	No hits observed in target area
18 Jul 49				45	3	31,500	120	-33	Fuel ignited and sustained burning
						Remote Fire Control			
29 Jul 49				3	3	34,000	135	-40	No ignition
2 Aug 49				6	0	34,500	140	-30	Control and aircraft plane malfunction
5 Aug 49				5	5	34,000	140	-30	Fuel ignited and sustained burning; drone lost in marsh
19 Aug 49	20 mm M3 T31	M97 T23 HEI		1	1	32,500	135	-46	Gun malfunctioned; no ignition
2 Sep 49				0	0	30,250	145	-42	Gun malfunctioned; no ignition
10 Sep 49				1	1	34,000	140	-44	Gun exploded; no ignition; plane crashed at sea
14 Sep 49				3	3	32,000	140	-42	No ignition
20 Sep 49				3	3	32,500	135	-48	No ignition; severe landing damage
28 Sep 49		M96 Incendiary		3	3	32,000	140	-43	Fuel ignited and sustained burning; drone damaged on landing
2 Nov 49	Cal .50 M3	M23 T48 API	JP-1	0	0	30,000	140	-43	Gun malfunction; gun heater failed
3 Nov 49				3	3	28,500	135	-31	No ignition
3 Nov 49			JP-3	0	0	30,000	145	-34	Gun malfunction; loaded backward
7 Nov 49				3	3	30,000	145	-31	Fuel ignited and sustaining burning
27 Dec 49	Cal .60 T17E3	T36 Incendiary	JP-1	0	0	-	-	-	Drone crashed in field; throttle failure
25 Jan 50				3	3	30,000	140	-30	Fuel ignited and sustained burning; drone crashed at sea
8 Feb 50		T39 API		5	5	32,000	120	-39	No ignition; drone landed wheels up; hydraulic leak
23 Feb 50			115/145	3	3	29,400	145	-44	Fuel ignited and sustained burning
2 Mar 50		T36 Incendiary		3	3	30,500	150	-35	Fuel ignited and sustained burning; drone lost at sea
6 Mar 50	20 mm M3 T31	M97 T23 HEI	JP-3	0	0	26,000	145	-26	Drone lost at sea; engine failure
10 Mar 50				0	0	-	-	-	No test; drone losing oil
14 Mar 50				0	0	-	-	-	No test; drone losing oil
24 Mar 50				1	1	31,200	160	-45	No ignition; drone returned to base

In addition, this fuel appeared to burn at a higher temperature than the other two test fuels, as evidenced by the greater destruction wrought by approximately an equal amount.

The maximum true altitude* at which positive results were obtained was 34,000 feet, this being the approximate operating ceiling of the control photographic aircraft.

Tests at Eglin Air Force Base

B-17 Drone Firing Tests. The purpose of these tests, conducted in April and May 1950, was to determine whether standard small arms incendiary ammunition was capable of initiating a sustained fuel fire under flight conditions at altitudes in excess of 35,000 feet in both purged and unpurged wing cavities.

The aircraft tested was a B-17 drone (Figure 1) equipped with remote control devices, three caliber .50 M2 guns with automatic chargers, two television cameras, and an exhaust gas purging system. Tokyo fuel cells in the wing of the aircraft were partially filled to one-tenth their capacity with 100/130 octane gasoline (Spec AN-F-48) and were purged internally and externally with exhaust gases.

A multiple-shot technique was used in these tests. The first test was not valid since the rounds functioned on the spar cap; the test was therefore not considered.

In the second test, two rounds of caliber .50 M23 ammunition were fired into the left outboard Tokyo fuel cells (as shown in Figure 1) 90 seconds apart at a pressure altitude** of 35,400 feet. These cells were purged. Both rounds were seen to

*True altitude is the height above mean sea level.

**Pressure altitude is the height above the standard datum plane, a theoretical plane where atmospheric pressure is 29.92 inches of mercury and the temperature is +15° C.

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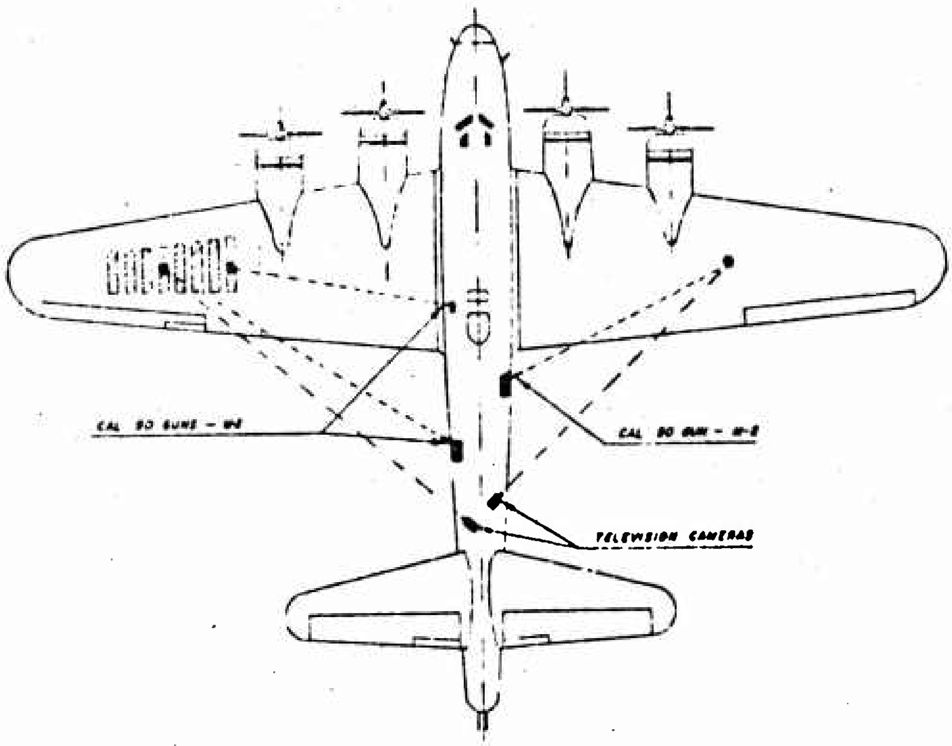

Figure 1. B-17 drone aircraft

function, but no fire or smoke was observed by the television cameras and trailing fighter aircraft. Three minutes after the second round was fired, a third round was fired into the left inboard Tokyo fuel cells, which were externally purged. The round functioned and fuel was seen to spray from the 4 in. x 6 in. projectile entry hole.

Thirty seconds later a fourth round was fired into the same cells. This round also functioned, but again no fire or smoke was seen. Approximately five minutes after the fourth round was fired, the left wing broke upward and tore away. As the wing tore away, the remaining end of the wing was enveloped in smoke and fire. The aircraft dropped into a tight vertical spin, fell about 5000 feet, and was completely disintegrated by a violent explosion. The telephoto camera in the B-29 photographic aircraft was operative for the last five-minute period and examination of the film revealed the presence of fire in the wing prior to breakup.

A review of the B-17 drone firing tests under multiple-shot conditions shows that

1. It is possible to ignite and sustain a destructive fuel fire with caliber .50 M23 incendiary ammunition at an altitude of 34,500 feet.

2. External purging of fuel cell areas is not effective in preventing sustained fires.

<u>Trapeze Target Firing Tests</u>. These tests were conducted at Eglin Air Force Base from 1951 to 1955.

1. Caliber .50 M23 Multiple-shot Firing Tests - The purpose of these tests was to evaluate the effectiveness of caliber .50 M23 incendiary ammunition under flight conditions. This ammunition was fired into both purged and unpurged tanks containing jet fuel. The target used (Figure 2) consisted of a 165-gallon F-80 type wing tip fuel tank, modified to simulate structural characteristics found in aircraft. A 40-gallon, B-25 auxiliary self-sealing fuel cell with a 0.072 inch thick covering of dural was located within the tank. A backing board of fiberglas was interposed between the fuel cell and the dural. The nose of the tank (0.064 inch dural) served as the functioning plate for the ammunition. Stand-off distances from function plate to fuel varied between 20 and 28 inches. The results of these tests, which are reported in Table II, indicate that flash fires can be obtained in vapor-filled compartments by incendiary ammunition at altitudes up to 15,000 feet. In all known cases, according to Eglin Air Force Base data,

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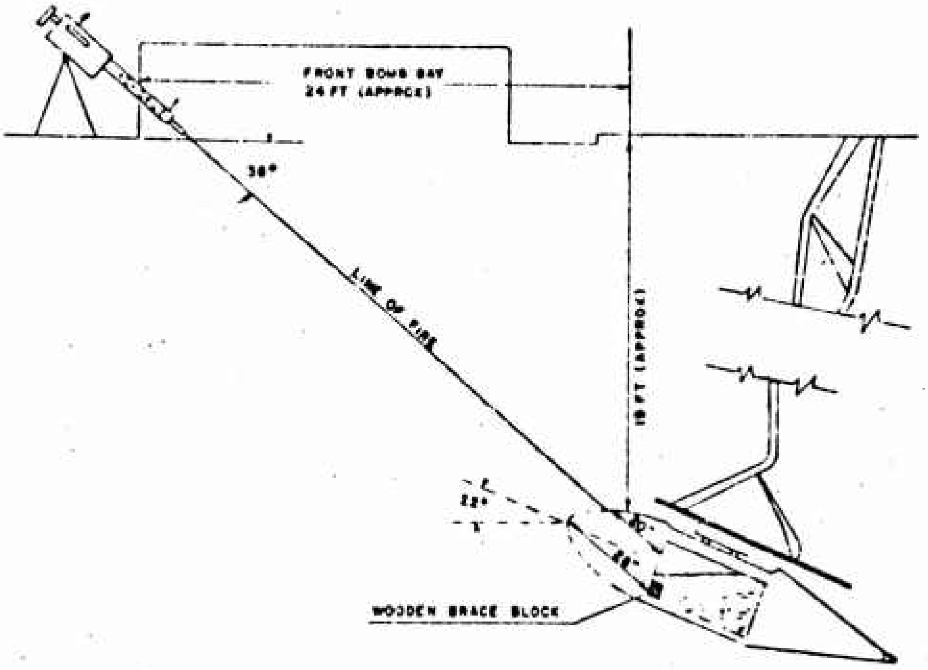

Figure 2. Schematic diagram of trapeze target

when a round entered the vapor area above the fuel level and when there was no previous fuel leakage, there was no evidence of a flash fire. However, where a round had caused fuel leakage, the following round gave evidence of causing flash fires as recorded by an increase in the cavity temperature. The one sustained fire at 15,000 feet resulted from a leakage of fuel in firing a previous round.

2. 20 mm Firing Tests - The purpose of these tests was to evaluate the effectiveness of 20 mm M97 HEI and 20 mm M96 incendiary ammunition under flight conditions. The target used (Figure 2) was the same as that described for caliber .50 M23 ammunition in multiple-shot firing tests. The 22° altitude shown in Figure 2 was changed to 6° to insure ammunition impact below fuel

Table II. Trapeze Target Firing Data, Eglin Air Force Base

Mission No.	Pressure Altitude (ft)	Indicated Air Speed (knot)	Air Temp (°C)	Fuel Type	Fuel Amount (gal)	Filler Cap	Inerted (CO_2)	Round No.***	No. of Rounds Fired/Mission	Pressure (in. Hg) Cavity Min	Pressure (in. Hg) Cavity Max	Pressure (in. Hg) Vapor Min	Pressure (in. Hg) Vapor Max	Cavity Temp (°C) Min	Cavity Temp (°C) Max
Caliber .50 M23															
1	35,000	-	-	JP-5	20	On	No	-	3	-	-	-	-	-	-
2	35,000	-	-	JP-5	20	On	No	-	1	-	-	-	-	-	-
3	14,350	185	6	JP-4	20	Off	No	3	3	17.5	17.5	19.0	21.0	6	37
4	16,000	183	2	JP-4	20	Off	No	4	6	19.2	19.3	16.1	16.8	2	40
	16,100	181	4	JP-4	20	Off	No	5	6	19.1	19.2	16.2	16.6	10	56
	16,000	180	4	JP-4	20	Off	No	6	6	19.1	19.2	16.1	16.1	14	52
5	34,220	166	-34	JP-4	20	On	Yes	1	1	15.5	16.1	7.3	8.2	-32	-10
6	12,600	193	4	JP-4	50	Off	No	3	3	19.1	19.4	18.3	18.5	6	36
7*	15,000	187	2	JP-4	50	Off	No	1	3	18.1	19.1	16.7	16.9	2	3
	15,000	184	2	JP-4	50	Off	No	3	3	19.0	19.2	16.7	16.8	2	60
20 mm M97															
9	15,000	-	-	JP-4	50	Off	No	-	1	-	-	-	-	-	-
10	15,000	-	-	JP-4	50	Off	No	-	1	-	-	-	-	-	-
20 mm M96															
8*	15,050	187	1	JP-4	50	Off	No	1	1	16.5	16.7	19.1	20.0	0	60
11*	15,000	-	-	JP-4	50	Off	No	-	1	-	-	-	-	-	-
12	25,320	182	-18	JP-4	50	Off	No	1	1	11.2	11.3	10.4	10.6	-12	40
13**	24,900	165	-14	JP-4	50	Off	No	1	1	11.3	11.4	10.8	10.8	-6	30
14	25,140	167	-14	JP-4	50	Off	No	1	1	-	-	12.0	12.0	-8	6
15	25,200	185	-16	JP-4	50	Off	No	1	1	10.9	10.9	11.3	11.6	-10	44
16	25,000	-	-	JP-4	50	Off	No	-	1	-	-	-	-	-	-
17	23,300	176	-14	JP-4	50	Off	No	1	1	10.9	10.9	11.2	11.2	4	8
18	25,020	181	-4	JP-4	50	Off	No	1	1	12.1	12.1	12.4	12.8	-2	20
19	25,300	182	-8	JP-4	50	Off	No	1	1	12.1	12.2	12.4	12.6	-4	4
20	25,700	176	-16	JP-4	50	Off	No	1	1	10.6	10.7	10.3	10.3	-2	4
21	25,740	173	-6	JP-4	50	Off	No	1	1	10.6	10.7	11.1	11.3	-4	6
22	18,500	180	-2	JP-4	50	On	No	2	2	13.8	14.0	14.0	15.0	2	64
23	20,050	182	-4	JP-4	50	On	No	1	1	13.3	13.6	13.7	14.2	6	40
24	20,150	175	-6	JP-4	50	Off	No	1	1	13.4	13.5	13.9	14.1	4	60

*Sustained fire occurred on this mission.

**Sustained fire occurred on this mission; attitude of target was changed at this point.

***Round from which data were obtained (information not obtained for each round fired)

level. The results are reported in Table II, examination of which shows that sustained fires can be obtained up to 24,980 feet with a single round of 20 mm M96 incendiary ammunition. Good incendiary functioning of the M96 ammunition was noted both at entry and exit holes. Single-shot sustained fires were obtained at altitudes of 15,000, 15,050, and 24,980 feet.

From the limited firings made with the 20 mm M97 HEI ammunition, it was evident that the M505 fuze was too quick in action and that the functioning distance of 20 to 28 inches (the distance between the point of entry into the target and the fuel cell wall) defeated the ability of the round to cause fires under the conditions of the test.

3. Caliber .50 M23 Single-shot Firing Tests - This investigation of aircraft fuel fires was conducted to determine the maximum altitude under flight conditions at which fires could be initiated by firing single-shot service, caliber .50, M23 incendiary ammunition into a target simulating the construction of a wing fuel cell. The target (Figures 3 and 4) was similar to that presented to a bomber tail defense shot against an opposing fighter attacking from the six o'clock position. The target was suspended below the rear bomb bay of a B-29 aircraft.

Prior to flight tests at altitude, ground firings were conducted against the target in order to obtain maximum functioning effectiveness of the ammunition. Various adjustments in junction plate, thickness, and angles were required prior to final target design.

Fifteen aerial firing missions were flown, during which the target sustained good hits at pressure altitudes varying from 9500 to 25,200 feet, and at indicated air speeds. The results of these single-shot firing missions are presented in Table III.

These tests show that sustained fires were obtained up to an altitude of 20,500 feet, and above that altitude flash fires were obtained up to 25,200 feet. Damage by fire was greater at the 10,000-foot level than at higher altitudes. Film assessment disclosed a definite relationship between the intensity of the fire, length of flames trailing the target, and the altitude at which the aircraft

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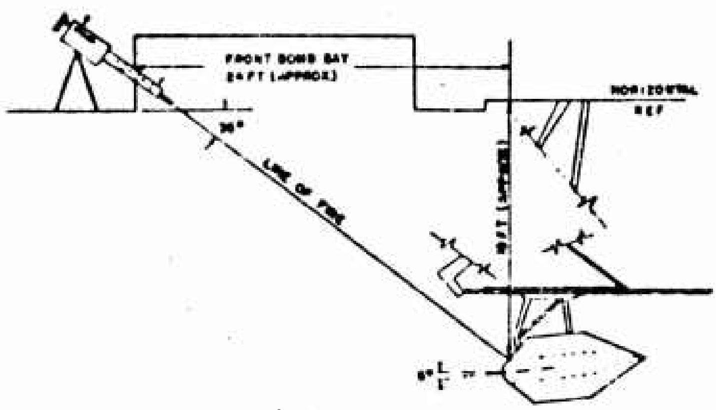

Figure 3. Modified B-29 trapeze target

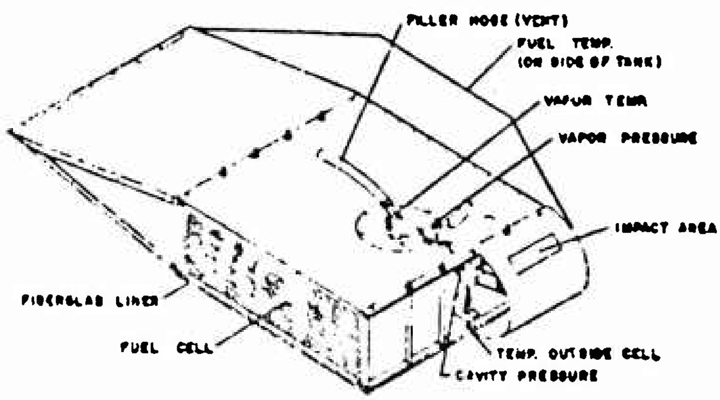

Figure 4. Cut-away view of modified B-29 fuel cell target

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Table III. Aerial Firing Data, Eglin Air Force Base

Mission No.	Pressure Altitude (ft)	Indicated Air Speed (knot)	Air Temp (°C)	Fuel (gal)	Type Fire	Pressure (in. Hg) Cavity	Pressure (in. Hg) Vapor	Cavity Temp (°C)
1	10,000	No data	4.0	12.0	None; no fair hit	- - - - - No data - - - - -		
2	10,150	No data	0.5	10.0	Sustained	- - - - - No data - - - - -		
3	10,200	168	2.0	10.0	"	- - - - - No data - - - - -		
4	10,000	169	4.8	12.0	None; no fair hit	- - - - - No data - - - - -		
5	10,000	165	7.8	11.0	Sustained	- - - - - No data - - - - -		
6	19,555	161	-16.5	12.0	Sustained	- - - - - No data - - - - -		
7	24,700	156	-25.5	10.0	Flash	- - - - - No data - - - - -		
8	25,200	165	-29.0	12.0	"	11.30	11.50	-11
9	25,000	165	-25.0	10.0	"	No data	11.48	-10
10	22,500	161	-23.0	12.0	"	- - - - - No data - - - - -		
11	20,800	165	-15.8	12.0	Sustained	13.27	13.77	0
12	21,550	159	-18.8	12.5	Flash	No data	11.10	-2
13	21,200	154	-11.0	12.0	"	13.20	13.29	0
14	20,900	156	-10.0	12.0	Sustained	13.22	14.10	0
15	9,500	157	10.0	12.0	"	21.00	21.11	No data

Notes:

JP-4 fuel was used on all missions.

Due to instrumentation failure, no fuel and vapor temperature data were obtained.

was flown. Inspection of the target after each mission revealed approximately the same rivet failures which permitted air of unknown velocities to circulate within the target after projectile impact.

Subsequently, this type target was strengthened to eliminate rivet failures and other structural weaknesses. The following types of ammunition were then fired single-shot against the target:

1. Caliber .50 M23 incendiary (standard).

2. Caliber .50 M23 incendiary containing 10 grains (nose mix) IM-163 and 94 grains (body mix) IM-162. (Both of these mixes contain zirconium.)

3. Caliber .50 M8 API (standard).

4. Caliber .50 M20 APIT containing IM-163.

5. 20 mm M97A1 HEI with M505 fuze.

A total of 37 single-shot aerial firing missions at density altitudes* from 10,900 to 27,700 feet was flown and the results are recorded in Table IV. They indicate that sustained fires, with the type of target employed, cannot be produced (a) with caliber .50 M23 incendiary service ammunition containing standard mix (IM-28) at density altitudes above 22,600 feet, (b) with caliber .50 M23 incendiary ammunition containing zirconium mixtures at density altitudes above 25,400 feet, or (c) with 20 mm M97A1 ammunition with the M505 fuze at density altitudes above 15,000 feet. No sustained fires could be initiated with caliber .50 M20 APIT ammunition containing a zirconium mixture at density altitudes of 17,700, 20,600, and 22,600 feet, or with caliber .50 M8 API service ammunition at density altitudes of 21,300 or 23,400 feet.

Firing projectiles into the leading edge of the target did not provide an optimum condition for initiating and sustaining a fuel fire. Due to target structural damage, the volume and velocity of air flow through the structure immediately following the projectile burst created a ram-air flame blowout effect so that some fires that might have been sustained were quickly extinguished. This condition was more prevalent with the 20 mm ammunition, due probably to the larger entry hole.

4. Test of Special Navy Rod Ammunition at High Altitudes - This test was conducted to determine the effectiveness of special Navy Rod projectiles in initiating fuel fires at high altitudes. These rods were designed for guided missile war head use and were made of one piece of steel with an approximate weight of 97 grains. The target used (Figures 3 and 4) was the same as that described in the previous test except that the fuel cell was filled with approximately 35 gallons of JP-4 fuel.

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*Density altitude is the pressure altitude corrected for temperature variation at flight level.

Table IV. Aerial Firing Data - Eglin Air Force Base

Mission No.	Altitude (ft) Density	Altitude (ft) Pressure	Indicated Air Speed (knot)	Air Temp (°C)	Type Fire	Cavity Temp (°C)	Pressure (in. Hg) Cavity	Pressure (in. Hg) Vapor
			Caliber .50 M23 Incendiary Service					
1	11,000	10,000	No data	4.0	No fair hit	- - - - - -	No data	- - - - - -
2	10,900	10,150	No data	0.5	Sustained	- - - - - -	No data	- - - - - -
3	11,100	11,100	162	2.0	"	- - - - - -	No data	- - - - - -
4	11,000	10,000	169	4.0	No fair hit	- - - - - -	No data	- - - - - -
5	11,500	10,000	165	7.0	Sustained	- - - - - -	No data	- - - - - -
6	21,000	19,550	161	-16.5	"	- - - - - -	No data	- - - - - -
7	25,650	24,700	156	-25.5	Flash	- - - - - -	No data	- - - - - -
8	25,900	25,200	165	-29.0	"	-11	11.90	11.50
9	26,100	25,000	165	-25.0	"	-10	No data	11.40
10	25,400	22,500	161	-23.0	"	- - - - - -	No data	- - - - - -
11	21,900	20,800	165	-15.8	Sustained	0	13.27	13.77
12	22,700	21,550	159	-18.0	Flash	-2	No data	11.10
13	23,150	21,200	154	-11.0	"	0	13.20	13.29
14	22,600	20,900	156	-10.0	Sustained	0	13.22	14.10
15	11,100	9,500	157	10.0	"	No data	21.00	21.11
			Caliber .50 M23 Incendiary w/Zr mix					
16*	Aircraft did not maintain alt			-25.0	Sustained	- - - - - -	No data	- - - - - -
17	27,700	25,000	156	-11.0	No fair hit	-8	10.17	10.49
18	26,500	24,950	159	-22.0	Flash	- - - - - -	No data	- - - - - -
19	25,300	23,200	158	-10.0	"	- - - - - -	No data	- - - - - -
20	25,400	23,000	162	-9.0	Sustained	- - - - - -	No data	- - - - - -
21	26,000	23,350	162	-8.0	Flash	- - - - - -	No data	- - - - - -
22	25,400	22,800	161	-6.0	Sustained	3	12.40	12.60
23	26,900	23,200	162	-3.0	Flash	- - - - - -	No data	- - - - - -
24	25,950	22,700	158	0.0	"	2	14.31	14.29
25	24,[illegible]00	22,600	156	-17.0	"	- - - - - -	No data	- - - - - -
26	23,200	22,800	164	-8.0	"	- - - - - -	No data	- - - - - -
27	24,000	21,600	161	-5.0	"	No data	12.40	12.50
			Caliber .50 M20 APIT w/Zr mix					
28	21,600	20,800	165	-10.0	Flash	No data	12.25	12.95
29	20,600	18,000	160	-6.0	"	No data	13.05	13.10
30	17,700	16,400	161	-6.0	"	No data	13.20	13.20
			Caliber .50 M8 API Service					
31	23,400	20,500	167	0.0	Flash	- - - - - -	No data	- - - - - -
32	21,300	18,200	155	2.0	"	- - - - - -	No data	- - - - - -
			20 mm M97A1 w/M505 Fuze					
33	24,800	23,150	155	-17.0	Flash	-12	11.53	9.93
34**	20,000	17,600	160	0.0	"	No data	15.10	13.90
35	11,000	13,900	162	3.0	"	5	16.90	15.50
36	13,000	13,000	165	7.0	Sustained	10	18.00	17.50
37	16,900	13,800	174	-6.0	Flash	No data	18.00	14.90

Note: Lot R & B 80-53 used in missions nos. 16 to 27, incl, Lot FAX 5C-8179 in missions nos. 24 to 27, incl

*Density altitude at time of firing, 26,100 ft

**Target jettisoned after firing because excessive vibration of target and trapeze created a hazard.

Nine single-shot firing missions were flown and the results, which are recorded in Table V, show that the target sustained good hits at density altitudes varying from 10,000 to 30,200 feet. Only one sustained fire was obtained and this was not determined until the aircraft had descended from an altitude of 15,000 to 9000 feet, when a well developed fire became visible. These results show that this special projectile was not reliable in initiating sustained fires at the aforementioned altitudes under the conditions of the test.

Table V. Aerial Mission Data on Special Navy Rod Ammunition

Mission No.	Density Altitude (ft)	Air Temp (°C)	Indicated Air Speed (Knot)	Barometric Pressure (in. Hg)	Type Fire
1	15,000	1.0	174	No data	Sustained, but did not become visible until about 9000-ft pressure altitude on descent of aircraft to field
2	28,600	-21.0	156	No data	Flash of 1.2 sec duration
3	30,000	-25.0	155	9.61	Flash of 1.2 sec duration
4	25,000	-16.0	154	10.08	Flash of 1.2 sec duration
5	30,000	-23.0	156	9.10	Flash of 1.2 sec duration
6	30,000	-24.0	153	9.15	Flash of 1.2 sec duration
7	30,200	-27.5	156	8.90	Flash of 1.2 sec duration
8	15,000	2.0	160	17.15	Spasmodic of 28.0 sec duration
9	10,000	6.0	164	20.15	Spasmodic of 6.0 sec duration

Summary

The B-17 and F6F drone firing tests show clearly the possibility of sustained fires at 34,500 feet, whereas results from later trapeze target firing tests show the absence of sustained fire above 24,980 feet with identical types of ammunition. It can be inferred that this difference is a function of target configuration and air speed

rather than ammunition type or composition of the incendiary mixture. However, given identical conditions, it has been shown that ammunition containing zirconium incendiary mixtures produced sustained fuel fires at slightly higher altitudes than ammunition containing conventional incendiary mixtures.

An additional series of tests will be conducted at Eglin Air Force Base. The tests will be made with a new type target (Figure 5) suspended below the wing of the B-50 aircraft (Figure 6) so that the waist gun can be used to fire at the trailing edge of the target.

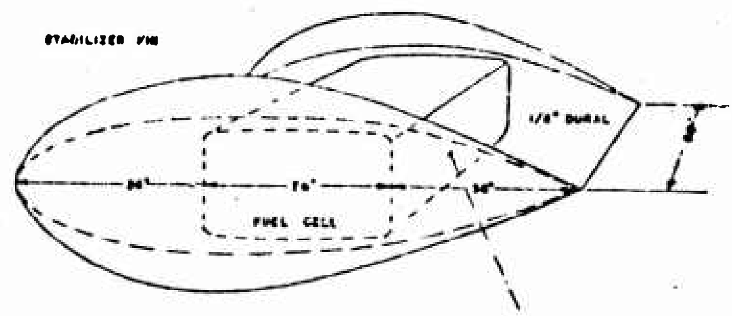

Figure 5. Fuel cell target to be used at Eglin Air Force Base

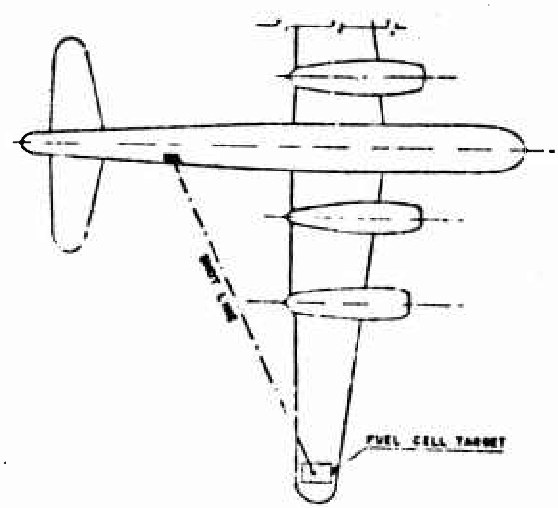

Figure 6. Method of suspending fuel cell target below B-50 aircraft

AERIAL COMBAT FIRING RECORDS

Analysis

This section deals mainly with an analysis of combat firing records obtained from the Korean conflict. Some data are available from World Wars I and II but this material does not relate too well to present aircraft.

Records of aerial combat in Europe during World War II contained data on the effectiveness of the various caliber .50 incendiary and API ammunition at relatively high altitudes.

Some of the data, as outlined in Office, Chief of Ordnance report entitled "Record of Army Ordnance Research and Development," are presented in Table VI, and an analysis of these data shows that all of the reported combat took place at altitudes over 15,000 feet and the evidence clearly shows fire kills at altitudes of 30,000 feet. It must be kept in mind that (a) the aircraft speeds during this period were in the range of 200 to 300 miles per hour, (b) aircraft were using high-octane gasoline (similar to JP-3), (c) air frame construction was usually much less sturdy than that of present aircraft, and (d) the number of strikes (rounds impacting on the target) was undoubtedly higher than in present combat.

Data obtained from the Korean conflict concerning the vulnerability of aircraft to incendiary ammunition at high altitudes confirmed results from World War I..

A detailed study was made of the air-to-air war in Korea by the Institute for Air Weapons Research, University of Chicago. Because of the importance of such data to the Institute, the Combat Analysis Group was organized within it for the study of the Korean aerial combat films.

On 17 January 1952, Air Force Regulations 95-13 set forth the purpose and function of the group by stating that "the Combat Analysis Group will provide scientific assessment of all armament recording photography. Data resulting from these studies will be

utilized in future operational planning and the establishment of trends in Air Force research and development in the fields of weapon effectiveness and aircraft vulnerability."

Table VI. Results of 20 Combat Missions Employing the T16 (M8) API Bullet during World War II
(Taken from "Record of Army Ordnance Research and Development")

Date of Mission	No. of Rounds Fired	Range (yd)	Altitude (ft)	Claim
3 Oct 43	360	250-150	16,000	1 enemy aircraft destroyed
Strikes were easily seen on enemy aircraft and pieces were seen to fall off (pilot believed armor-piercing quality effective)*				
8 Oct 43	665	150-200	19,000-23,000	2 ME 109s destroyed and 1 damaged
Ammunition very effective; both enemy aircraft destroyed caught fire; strikes easily seen				
8 Oct 43	163	150-200	24,000-25,000	1 enemy aircraft, probable
Saw good strikes forward of cockpit; also saw smoke and pieces fall from enemy aircraft; ammunition enables pilot to see more strikes				
8 Oct 43	841	150-200	24,000-25,000	1 ME 109 destroyed
Ammunition superior; pilot saw smoke and pieces fall off when enemy aircraft was hit; strikes easily seen				
8 Oct 43	150	1000-1500	18,000	None
No strikes observed; no comments				
4 Oct 43	1435	300 or less	20,000-22,000	3 ME 110s destroyed
Apparently the ammunition did the same amount of damage as regular ammunition, but it made more of the strikes visible than does regular ammunition				

*Statements represent pilot's remarks.

Table VI. Results of 20 Combat Missions Employing the T16 (M8) API Bullet during World War II (Cont'd)

Date of Mission	No. of Rounds Fired	Range (yd)	Altitude (ft)	Claim
27 Sep 43	965	250-75	25,000	1 ME 109 destroyed and 1 damaged

Many incendiary strikes were observed on each wing of one [illegible]ft. My range was too close when these hits were observed and no hits were seen on t[illegible] fuselage. I claimed this aircraft damaged. The second enemy aircraft I claimed destroyed. I was flying dead astern straight and level and took a 1-second burst or less. I saw many incendiary hits covering the fuselage from engine to tail. The aircraft immediately caught fire and [illegible]gan smoking. I pulled up and as I passed over the enemy aircraft, it exploded, causing my [illegible] to rock. I noticed white and dark smoke rising on each side of me as a result of the explosion. This is evidently very effective ammunition and I recommend it very highly.

16 Sep 43	58	Very great	25,000-24,000	None

No comment

10 Oct 43	510	Short	25,000	None

No comment

10 Oct 43	770	400-50	16,000	1 FW 190 destroyed

As all hits are visible and it appears that the incendiary effect is more violent and destructive in that it penetrates to the more vulnerable sections of the enemy aircraft in the interior, API ammunition is much superior to present ammunition in that it has both destructive and incendiary characteristics. Request that this ammunition be given the highest priority rating in a serious attempt to obtain it for all fighter aircraft.

10 Oct 43	78	150-200	24,000	1 damaged

Strikes seen; no time to note effect

10 Oct 43	521	350	17,000	1 ME 110, probable

This ammunition is as good as ordinary AP and I ammunition; would like to see all guns loaded with this ammunition

25 Oct 43	1008	350 or less	18,000	1 FW 190 destroyed

Would like this ammunition in all guns. All hits show strikes and in this case at each burst something cave off a enemy aircraft.

SECRET

Tabel VI. Results of 20 Combat Missions Employing the T16 (M8) API Bullet during World War II (Cont'd)

Date of Mission	No. of Rounds Fired	Range (yd)	Altitude (ft)	Claim
22 Oct 43	222	100-75	29,000	1 ME 109 destroyed
I saw strikes at the wing root, one small flash. A moment later I saw the white smoke from the Prestone burning. Since this was the first enemy aircraft I have fired at, I cannot say whether this ammunition is any better than or not as good as other ammunition.				
23 Oct 43	529	500-300	15,000	1 enemy aircraft destroyed
Have never shot airplane down before, but cannot complain of results in this case. Plane lit up with flashes from strikes and pieces came off quite soon.				
27 Sep 43	647	-	30,000	2 ME 109s destroyed
Both aircraft were hit on right side of fuselage near the top. A larger flash of incendiary was noted than usual. Hits were observed along the fuselage from front to rear. Well satisfied with the API ammunition				
27 Sep 43	253	400-250	25,000	None, pending film assessment
None. No observations made				
27 Sep 43	570	400-250	22,000	1 ME 109 destroyed
Opened fire from 15° deflection to dead astern on the same level with the target. Noticed many incendiary flashes covering the aircraft. As I broke away, a large fire broke out on the left wing root. I recommend this type ammunition very highly.				
27 Sep 43	799	900-600	31,000-23,000	1 ME 109 destroyed
This ammunition shows up strikes a great deal better and at excessive ranges; the effect of this ammunition at excessive range and with few guns firing was very good.				
10 Oct 43	168	-	25,000	1 ME 109 destroyed
No stoppages on this mission				

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From analysis of these films from gun cameras of fighter type aircraft, the Institute for Air Weapons Research was able to obtain range and angular position information, as well as bank angles and aim point wander and, of course, evidence of fire phenomena. The film has its limitations, however. Due to aerial combat maneuverability and the nature of the camera installation, hits could be scored on the target and kills obtained while the target MIG was outside the field of view of the camera. Structural damage or smoke, or even flame, might occur after the camera ceased to operate. This implies that the film records alone can never be used to state categorically that a kill did not occur.

For studies in such fields as vulnerability, fire control, and tactics, the altitude of the engagement is important. This cannot usually be obtained from film. Additional records are requisite, such as the pilot's Supplementary Combat Information Report (SCIR). Unfortunately, these reports were not submitted as frequently as the Institute for Air Weapons Research desired. The Institute has reports for only about 65 per cent of the sorties between March 1953 and the end of the war. However, the available SCIRs, in conjunction with combat film records establish a source of reference, and valid inferences relative to combat altitude may be made within limitations.

The operations in Korea, analyzed by the Institute of Air Weapons Research during the period June 1952 to July 1953, covered a total of 46,000 sorties and the expenditure of three million rounds of small arms ammunition. The study covered the aerial combat between the F-86 Sabre Jet and the Russian MIG-15. The survey covered many aspects of air warfare, such as the searching, positioning, and firing phases.

A comparison of firepower of the F-86 and MIG-15 follows.

	F-86	MIG-15	
	Caliber .50	23 mm	37 mm
Number of guns	6	2	1
Firing rate (round/sec)	105	27	7
Time of fire (sec)	17	6	6
Projectile weight (lb)	0.093	0.44	1.64
Muzzle velocity (f/s)	2780	2250	2250

The ratio of kill performance for the F-86 Sabre Jet to that for the MIG-15 has been reported at 13.7 to 1 during the period June 1952 to July 1953. This kill ratio is not representative of relative aircraft effectiveness, since much of the fighting was done near the Yalu River, requiring a much longer search phase for the F-86.

The reported altitudes at which combat took place (and these must be approximations due to rapid change in altitude under combat conditions) were as follows:

Firing Altitude (ft)	Total Engagements (%)
40,000 to 50,000	51
30,000 to 40,000	20
20,000 to 30,000	4
10,000 to 20,000	11
0 to 10,000	14

Based on combat films, opening ranges for all passes averaged 2900 feet, and passes in which hits were observed on film averaged approximately 1800 feet. Most of the attacks lasted from three to

seven minutes, with a rapid fall-off in the frequency of attacks of longer than ten minutes. It should be noted that 71 per cent of the total engagements were above 30,000 feet. In general, the attacks were at an angle-off of less than 10° with bank angles of -30° to +30°.

The types of phenomena associated with kills on the MIG-15, according to analysis of combat film, were classified as follows:

Smoke puff
Series of smoke puffs
Flame
Explosion
Sustained smoke
Debris

From combat film of one-hit attacks (attacks in which a hit registers on film as a single bright flash due, according to the Institute for Air Weapons Research, to the incendiary or explosive content of the round) approximately one-half evidenced some burning phenomena. This does not, however, exclude the possibility that other rounds may have hit the target aircraft that did not register on the film due to round type (a pure armor-piercing round will not register on film) or peculiar placement of the hit within the airplane itself.

Of significance, however, is the aforementioned fact that for the one-hit kills, fire phenomena was associated with the kill in one-half the cases. From these data and from the altitude data presented earlier, it is certain that fires were associated with kills at combat altitudes of over 30,000 feet. In two instances Supplementary Combat Information Reports completed by pilots after engaging the enemy, together with corroborative film data, indicated that sustained fire phenomena and explosion had taken place at altitudes as high as 41,000 and 42,000 feet in aerial combat in the Korean conflict. (Specifically, one U. S. Air Force pilot stated in the SCIR that his official kill of a MIG took place at approximately 42,000 feet. The evidence of this fire phenomenon was recorded on film record of this particular combat experience, as was the sustained fire kill of a MIG at a reported altitude of 41,000 feet by another USAF pilot.) The caliber .50 ammunition

belting for the M3 guns in both instances was typical, viz., 45 per cent M8 API, 26 per cent M1 incendiary, 19 per cent M21 tracer, and 10 per cent M20 APIT.

It is to be noted that such corroborative evidence was extremely rare in the analysis of Korean combat statistics as conducted by the Institute of Air Weapons Research. However, of significance in estimating the highest altitude at which MIG kills were recorded is the graphic representation of the average F-86 air-to-air combat mission (Figure 7) as determined in the analysis of combat flight data collected on various jet fighter aircraft during the Korean operations. This information is included in Wright Air Development Center Report TN-55-12, "Maneuver Load Data from Jet-Fighter Combat Operations." (U) May 1955, by Frank P. Gray. The major portion of the data for this report was recorded by the U. S. Air Force flight analyzer, an instrument capable of recording normal acceleration, air speed, pressure altitude, and time scale.

Of interest is the series of photographic frames (Figure 8) selected from the combat gun camera film records, corresponding to the flight analyzer record shown in Figure 9. These frames from the gun camera film show the destruction of a MIG-15 accredited to F-86F No. 52-4377 on 27 March 1953. Altitudes at time of firing bursts in this particular engagement were approximately 40,000, 32,000, and 22,000 feet with the strong possibility of sustained fire from the initial burst at 40,000 feet.

Summary

Aerial combat data obtained from the Korean conflict confirm results from World War II statistics, pointing to the vulnerability of aircraft to incendiary ammunition at high altitude.

Conclusive statements relative to the specific type of ammunition effective in producing an official kill of a MIG aircraft are indeed impossible from film data available. However, the fact that 81 per cent of the caliber .50 ammunition used in the Korean conflict was of incendiary type indicates that a majority of the kills with corrobative film evidence of fire phenomena was due to incendiary ammunition. A hit due to a round which contains no incendiary or explosive filler, such as a pure armor-piercing round, did not register on film.

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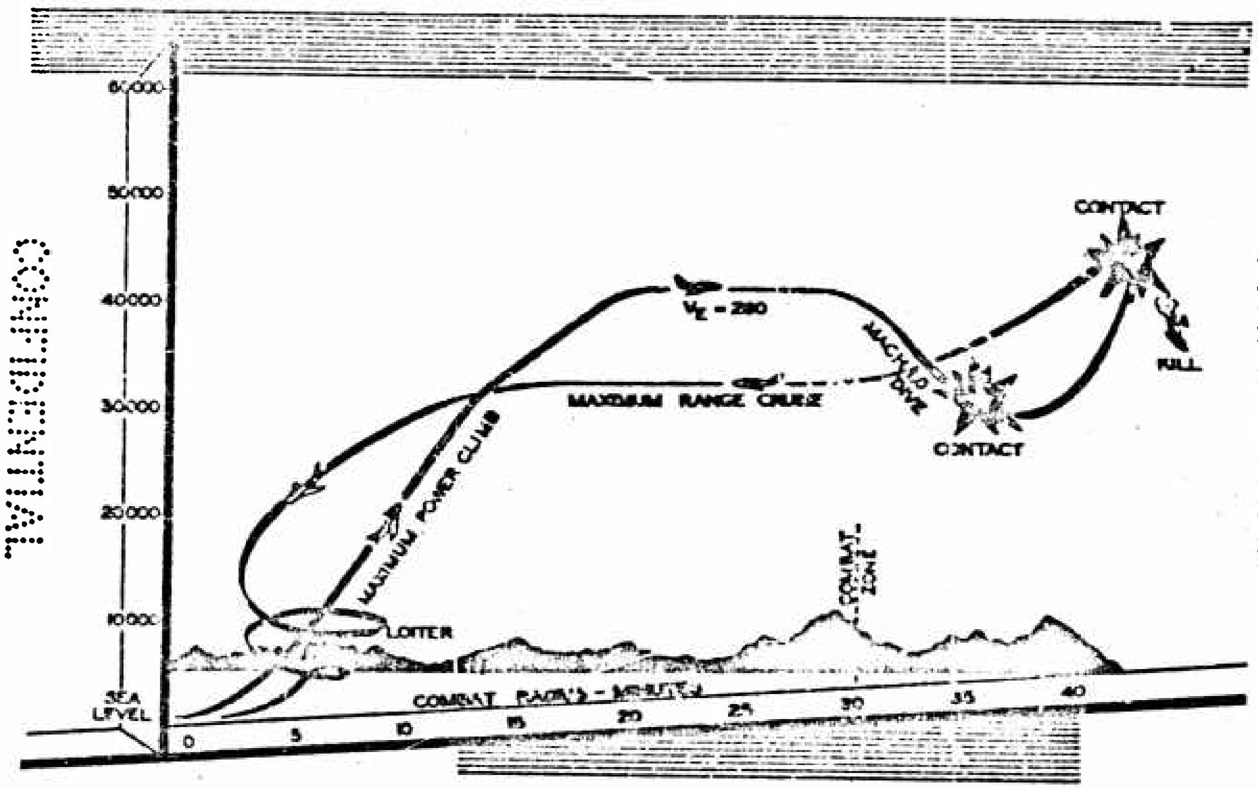

Figure 7. Average F-86 air to air combat mission

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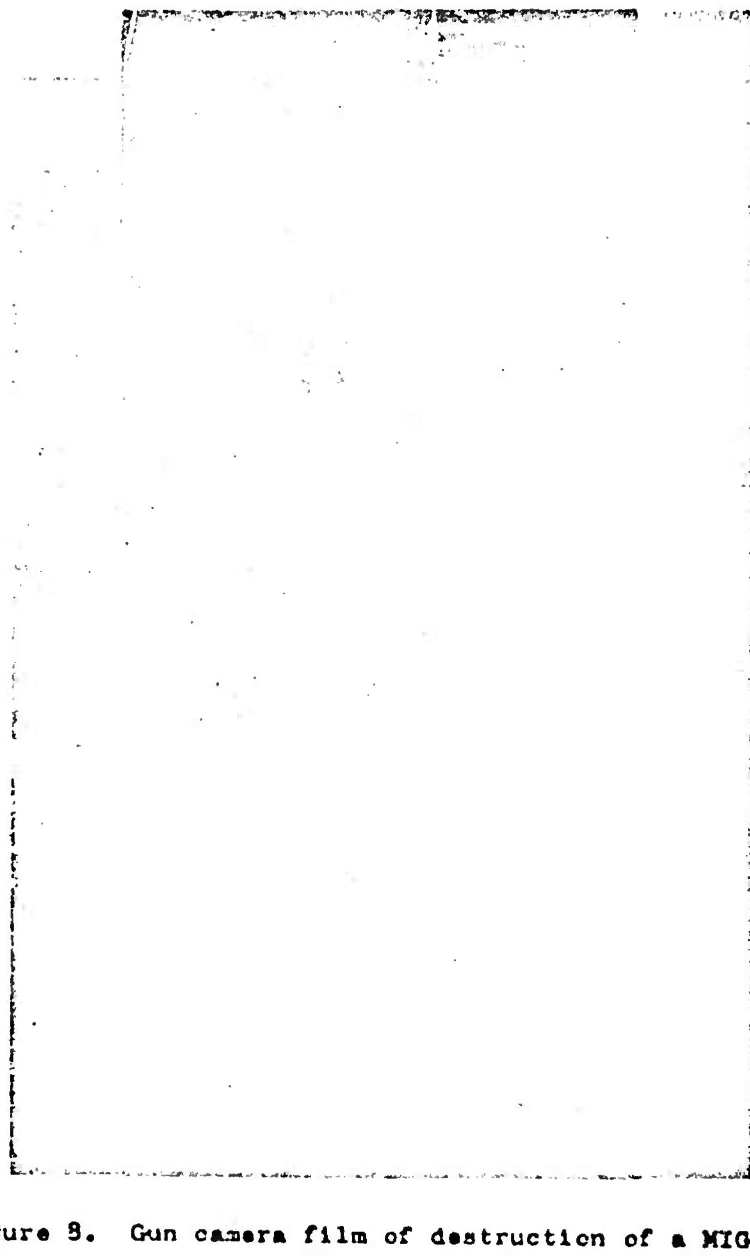

Figure 8. Gun camera film of destruction of a MIG-15

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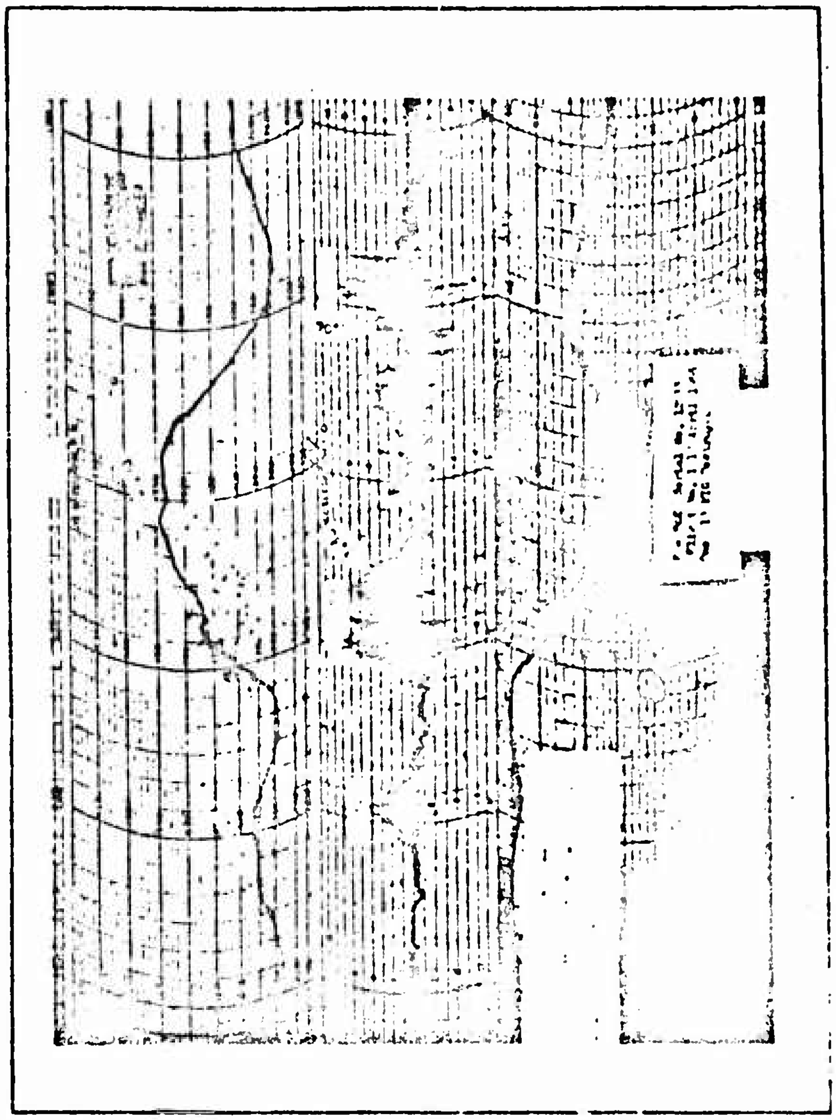

Figure 9. Photograph of flight record, air-to-air combat

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Indications are that MIG kills, with evidence accompanying of fire phenomena, were accomplished in the altitude range of 30,000 to 40,000 feet; however, there are at least two instances of kills at altitudes of 41,000 and 42,000 feet, respectively, recorded on combat film and corroborated by the SCIRs of the two pilots.

CONCLUSIONS

B-17 and F6F drone firing tests show that it is possible to sustain a destructive fuel fire with caliber .50 M23 incendiary ammunition at an altitude of 34,500 feet under multiple-shot conditions. Subsequent aerial trapeze target firing tests at Eglin Air Force Base show absence of sustained fire at 24,980 feet with identical ammunition. The differences in ignition appear to be a function of target configuration and air speed rather than ammunition type.

The B-17 and F6F drone firing tests seem far more realistic than the trapeze tests and represent true combat conditions to a far greater degree.

Analysis of Eglin Air Force Base results shows that incendiary ammunition containing zirconium has a consistent altitude ignition advantage over incendiary ammunition without zirconium.

In spite of the many variables inherent in the simulated firing tests and the uncertainty of definite altitude information in Korean Conflict aerial combat records, sustained fires, although limited in number, have been produced at approximately 42,000 feet.

It is concluded that the majority of kills with film evidence of fire phenomena was due to incendiary type ammunition.

FUTURE WORK

In future aerial firing tests at Eglin Air Force Base, the following types of incendiary ammunition should be tested in conjunction with the new fuel cell target (Figure 5):

1. 20 mm (HEI) M56 round with zirconium in the heel of the projectile.

2. 20 mm SID (structural and incendiary damage) experimental round.

3. Caliber .50 round containing incendiary composition and liquid halogen fluoride.

4. 20 mm round containing liquid halogen fluoride.

RECOMMENDATION

In view of the evident superiority of incendiary ammunition containing zirconium, a more widespread use of zirconium in standard incendiary compositions is recommended, such as the possible incorporation of this type composition in any multipurpose round development.

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